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The multicriteria approach in the architecture conception: Defining windows for an office building in Rio de Janeiro

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ABSTRACT

The aim of this paper is to apply a multicriteria method to define windows for an office building conceived for Rio de Janeiro, Brazil, under a compromise between landscape view, daylight level on work plan and energy efficiency. The intent is to select one from six proposed window solutions differing in window size, type of glass and solar shading devices. Several methods are applied to assess the performances for each of these criteria. Simulations are performed to obtain the annual indoor daylight levels. The measurement of the sight angles is carried out to quantify the landscape view. The prescriptive method from the Brazilian building thermal regulation is applied to assess the energy efficiency of each solution. The obtained results of the monocriterion analysis indicate several criteria conflict. In order to identify the compromise solution, the ELECTRE III method is adopted by means of the CELECTRE software. The results of the multicriteria analysis indicate that all solutions with solar shading have a more satisfactory overall performance than those with solar control glazing and without shading devices. Due to the large dimensions of the studied floor, large size windows with solar shading devices achieve better overall compromise results. It is concluded that the multicriteria approach is a very effective method to consistently analyze the solutions proposed for a problem and to assist designers to minimize the conflicts between criteria. It allows performing an integrated approach, enabling a more conscious, accurate and responsible decision making.

1. Introduction

Windows are envelope elements that play an important role in the building overall performance. They are responsible for regulating the indoor admittance of solar gains, daylight, wind, noise and pollutants, and can enable a visual integration with the exterior environment. Windows can also define the building formal aspect and impact the construction costs and the building life cycle.

The window design is a complex task due to the number of environmental and energy requirements considered when defining the frame type, the size, the location and the glazing type. In order to reconcile all design requirements, one may often face the following situation: the satisfaction of one requirement results in the dissatisfaction of others [1,2]. Rarely, it is possible to find a solution that satisfies all the involved criteria. Therefore, instead of searching for an ideal solution, one must pursue a compromise solution, which will minimize conflicts between the criteria and reach a whole formal coherence.

In event, it is difficult to identify a compromise solution in the design process due to the multiple criteria assumed. Generally, architects have difficulty listing possible conflicts between criteria and also quantifying its influence level on the building overall performance [2,3].

Recent investigations point out the multicriteria approach as an efficient way to overcome difficulties on decision problems [4,5]. This approach has been applied by other fields of knowledge such as economics, management and engineering, and in the last decades, it has been adopted in architecture to assist designers in the decision process involved in new buildings conception and refurbishment designs.

Most of the studies that apply the multicriteria approach in architecture [6–13] are focused on energy and environmental criteria, which reflects designers concern in conciliating so many conflicting criteria related to the building sustainability, as described by Wang et al. [5]. Some works apply multicriteria methods to aid the selection of bioclimatic strategies to improve the environmental comfort and the building energy efficiency [8]. There are also studies that apply this approach to identify a

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compromise solution for buildings envelopes, considering construction costs, environmental comfort, energy consumption and pollutant emissions [9,10,13]. The multicriteria analysis can also aid to reconcile budget constraints with the maximization of the number of credits for environmental building certifications, as demonstrated by Lacouture et al. [12]. This approach is also useful for the early design stage, when defining buildings shape to reduce energy consumption [6] or buildings arrangements to improve natural ventilation potential [7].

Some studies are focused on developing new methods or tools to apply the multicriteria approach [9,13], demonstrating them by means of architectural problems. Nevertheless, their applications do not suit architects skills, since it involves specific calculation knowledge such as genetic algorithms, neural network and fuzzy logic. On the other hand, Castro [2] presents a new tool based on the ELECTRE III method - the CELECTRE - that performs instantaneously all operations involved in the method, which enables architects to incorporate more easily the multicriteria approach into the design process.

This paper applies a multicriteria method to define a window solution for a new office building in Rio de Janeiro. The aim is to identify which of the compared window solutions best reconciles three of several criteria related to windows: landscape view, daylight level on work plan and energy efficiency.

One of the main contributions of this paper consists of presenting a case where a monocriterion analysis turns into a multicriteria analysis with the aim to evaluate more consistently the architectural solutions. It also presents an application of the software CELECTRE.

By incorporating this approach into the design process, we intend to emphasize its potential to assist the designers in the conception of a sustainable architecture.

2. The multicriteria approach

By means of a multicriteria approach, it is possible to analyze a problem from different points of view. In architecture, a multicriteria approach can be used to compare different solutions for a design problem considering simultaneously several constraint criteria, with the intent to identify a compromise solution.

There are several methods oriented to the application of a multicriteria approach, each one adequate to solve a sort of problem [4,5,14,15]. In common, these methods follow four basic steps.

1.*Alternatives' formulation*: definition of possible solutions for the problem by choosing some design parameters;
2.*Criteria selection and weighting*: definition of the criteria to assess the solutions and determination of their relative importance (weights);
3.*Monocriterion analysis*: solutions performance evaluation for each criterion; and
4.*Multicriteria analysis*: application of a multicriteria method to identify the best solution(s) for the problem.

The first three steps are the same for all methods and are essential procedures for a multicriteria method implementation [14].

When defining the solutions, one may consider some design constraints in order to compare only the feasible and efficient alternatives. The criteria selection and weighting may be carried out by all the actors involved in the design process (architects, engineers, constructors, estate developers) and also the ones whose life will be impacted by the building construction [2]. The complexity of a multicriteria analysis is proportional to the number of chosen criteria, especially if they present many conflicts among themselves. Also, different weights influence the multicriteria analysis results. Consequently, weighting should be done carefully to identify a suitable solution for the problem [5].

The monocriterion analysis may be carried out by means of several methods, including numerical simulation [7,8], interviews with specialists [16] and environmental and price database research [12,13]. Regardless of the subjective or objective nature of the criterion, the solution evaluation may provide a quantification of its performance to enable comparing them in the next step.

In order to accomplish the last step, one should elect a suitable method according to the problem specificities. Wang et al. [5] summarize the main methods, classifying them into three categories: elementary methods, methods in unique synthesizing criteria and outranking methods.

The elementary methods are applied to simplify complex problems for the selection of a preferred alternative. They do not necessarily consider the criteria weights and indicate a performance score for each solution. These methods are more suitable when considering few alternatives and criteria. Conjunctive, disjunctive, lexicographic, weighted additive are some methods that represent this category.

The methods in Unique Synthesizing criteria are more complex methods that apply optimization algorithms. It consists of ranking the solutions on a single scale according to their performance over a criterion at a time. After the monocriterion analysis, each solution scores are summed or averaged to obtain an overall score, which will be then compared to identify the compromise solution. Analytical Hierarchy process (AHP), TOPSIS, Multi-attribute value theory (MAVT) and Multi-attribute theory (MAUT) are some methods of this category.

The outranking methods propose the comparison of pairs of solutions over one criterion at a time in order to identify the preference of one alternative over another. The preference information is then aggregated across all criteria to obtain a solutions ranking. In the comparative analysis, an inferior performance on one criterion can be compensated by a superior performance on another. The ELECTRE family method and PROMETHEE are the most used outranking methods.

The present paper employs the ELECTRE III method [17]. It was chosen due to its capability of establishing a solution ranking under a weight ponder, and also due to the availability of the software CELECTRE [2,18] that allows performing instantaneously all operations involved in the method (comparison and distillation), which turns this last step resolution faster and easier for architects.

3. Materials and methods

The case study consists of a hypothetical 13 floors office building, conceived for the Rio de Janeiro city, Brazil ($-22°50'$ latitude, $-43°15'$ longitude). The main floor is about 19 m width, 55 m length and 2.60 m height (Fig. 1).

The windows are placed on the Southeast and Northwest facades, as well as along the perimeter of a central atrium, which divides the floor into two areas of about 22 m length each. The other facades are opaque and touch the lateral terrain boundaries.

The Southeast facade is turned to a beautiful landscape view composed by an ecological park – Flamengo Park – the Guanabara bay, the Sugar Loaf and, far-away, the Niterói city.

The Southeast and Northwest facades present two triangular vertical elements close to the windows edges. It will complement the shading action from the protection devices that will be proposed for the openings.

This building may be occupied annually from 8am to 6pm, except during lunch break (12am to 1pm) and weekends.

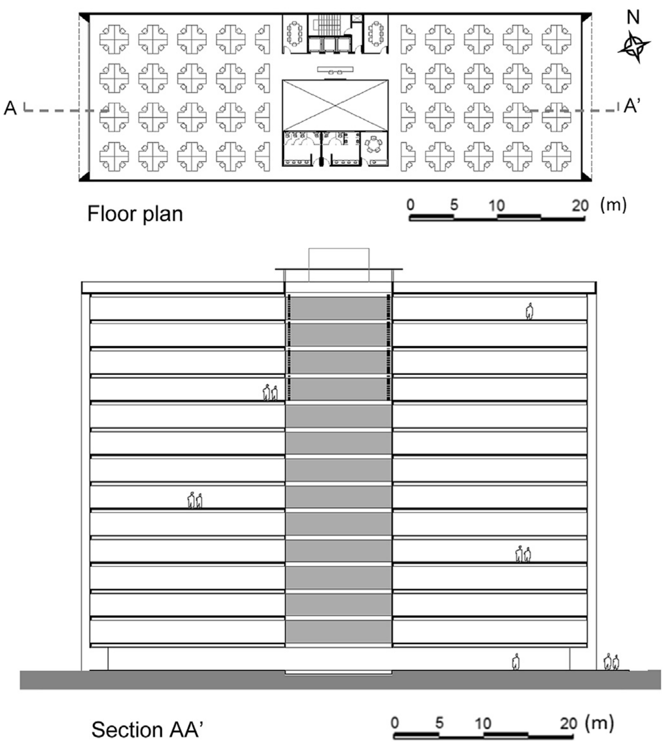


Fig. 1. Floor plan and section AA'.

The next section will detail the methodology, which follows the four basic steps required for a multicriteria analysis.

3.1. *Definition of the window solutions*

The first step consists of developing window solutions under the following requirements: it must be suitable to the tropical climatic conditions and it should assure the landscape view.

Based on these constraints, six window solutions are proposed, differing in window size, type of glass and solar shading device (Table 1). All the other parameters are fixed.

Concerning the window size, it is proposed two different Window Wall Ratio (WWR) – the ratio of the total window surface to the total facade surface – by varying the window height.

Regarding the solar shading, three variations are proposed, one of them without any shading device (S1 and S2). For the solar protected solutions (S3–S6), two devices are conceived – overhang and fixed horizontal fins – to prevent solar penetration during the building occupancy. Fig. 2 presents the shading masks generated by these shading devices, whose dimensions and spacing form maximum internal shade angles (α) of 65° and 0° for the Southeast and Northwest facade, respectively. The internal shade angle is measured between the facade plane and the plane that links the external extremity of the overhang to the bottom of the glass.

The selected types of glass (A and B) differ in light transmission. Shaded solutions adopt higher light transmission glass, while unprotected solutions present a glass with lower transmittance in visible range.

The glass proposed for the top of the central atrium is type B, which presents a high light transmission to ensure an efficient daylighting in zones distant from the windows.

By means of the sun path diagram, a solar penetration through the atrium openings was predicted from the 10th to the 13th floor. In order to prevent it, fixed horizontal fins were conceived with 25 cm width, spaced 12 cm from each other, and 30 cm from the window.

3.2. *Definition of criteria and weights*

Three criteria are considered for the analysis: landscape view, daylight level on work plan and energy efficiency.

The first two criteria are related to the occupants' visual comfort. They were selected due to the main building activity and its surroundings conditions. The energy efficiency is also a criterion of great relevance in this context, since office buildings are responsible for the second highest energy consumption in Brazil, just behind the residential sector [19]. In addition, the inclusion of this criterion in the analysis also reinforces the current initiatives regarding energy conservation, such as the creation of the Brazilian thermal regulation for office buildings.

Different weight scenarios are tested, in order to assess the weight influence on the final ranking (sensitivity assessment). It is proposed 13 distinct weight variation groups. One of them represents a scenario in which all criteria are considered equally important, i.e. they present the same weight. The other 12 groups were defined by giving priority to one criterion at a time, assigning weights two, three, four or five times greater than the weights of the other criteria.

3.3. *Monocriterion analysis*

In this step, the intent is to obtain the performances of the solutions considering each criterion at a time. Sight angles are graphically measured to compute the landscape view through the openings. Simulations are performed by means of the software Daysim 3.1 to assess the daylight profiles on the work plan. The prescriptive method from the Brazilian thermal regulation for commercial and public buildings [20] is applied to obtain an energy efficiency ranking for the solutions.

Along the next topics, a discussion is presented about the tools and input data used in the monocriterion analysis, as well as the assessment methodology applied to prepare its results to the final step. For all three criteria considered in the multicriteria analysis, it is presented a partial solution ranking, in order to highlight the conflicts between criteria.

3.3.1. *Landscape view assessment*

The way of evaluating the landscape view for each window solution is defined by considering how the human vision works. It is known that man sees the environment through a fixed angular field of view. However, the human vision is not limited to these angles if the movement of the eyes and head are considered [21].

In this way, the landscape view is quantified by measuring the free visual angles from indoor to outdoor. A point is fixed 4 m distant from each window (Southeast and Northeast) and 1.10 m elevated from the floor, representing a user seated in the first row looking at the opening.

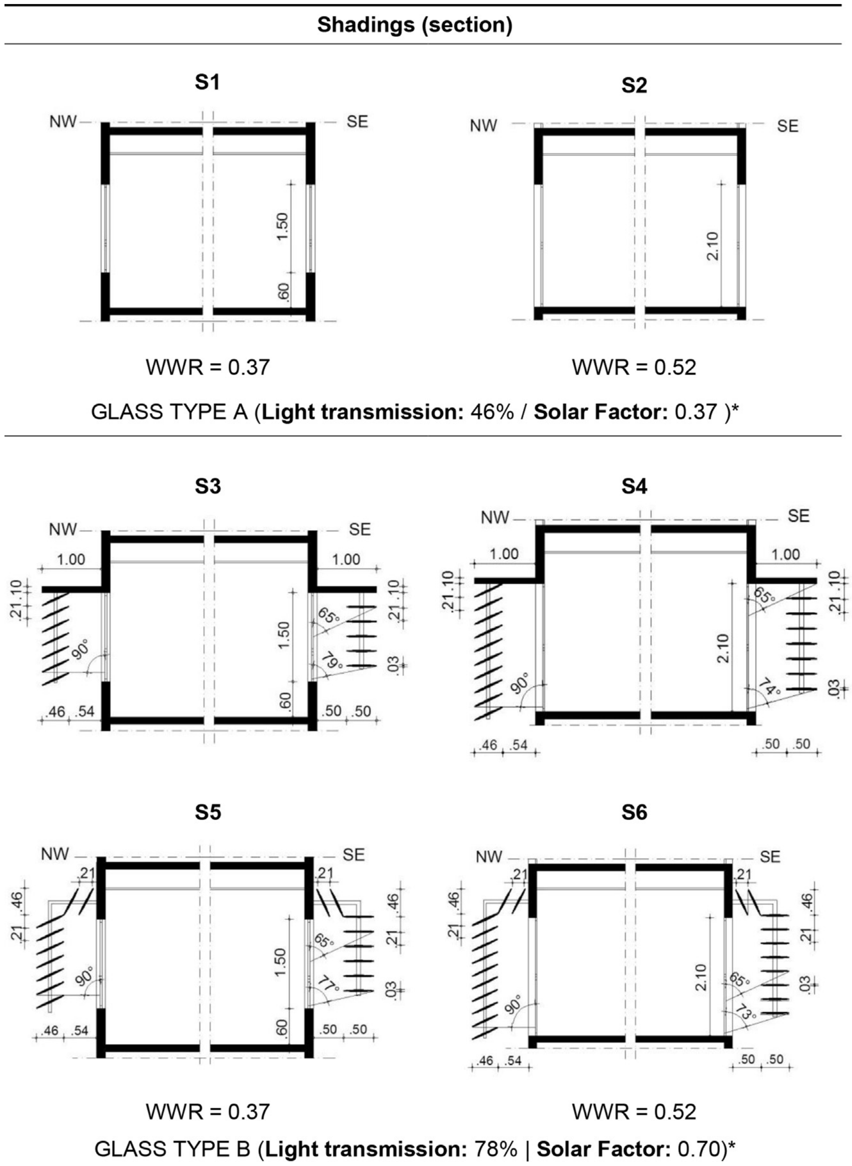
On the longitudinal section of the office space, it is drawn straight lines from the fixed points to the windows, representing the user field of view when moving his head and eyes. The lines deviate from the visual obstacles generated by the shading devices (Fig. 3). The horizontal angles – measured on plan – are not considered, as they are identical for all solutions.

The total visual angles represent the sum of all available visual angles for each solution.

3.3.2. *Assessment of the daylight level on work plan*

The assessment of daylight level on work plan is carried out by means of simulations with Daysim 3.1, a validated software [22] that combines the Radiance backward ray-tracer model and the Perez all weather sky model [23] to perform annual simulations of daylight level based on weather climate data. A comparison

Table 1
Summary of the window solutions.



* Although glass types are different in many other aspects, the table only provides the information required for the monocriterion analysis. Light transmission is an input data for Daysim simulations and WWR and Solar Factor are input data for the Energy efficiency assessment (RTQ-C).

between simulation and experimental results demonstrated that Daysim presents accuracy below 2 percentage points [22].

Six 3D models were built representing each different window solution. A 1.70 × 1.70 m grid over an area of 865.64 m^2 was considered, and placed 0.75 m height from the floor. The 3000 points grid follows the recommendations from the Brazilian standard for daylight indoor measurements [24].

The optical properties of each surface considered by Daysim are summarized in Table 2.

The weather climate file used in the simulations was the TRY (*Test Reference Year*) from Antonio Carlos Jobim International Airport (Galeao).

The simulation results (Tables 5, 6 and 8) are presented for three floors – 1st, 7th and 13th – in order to indicate the influence on indoor daylight caused by the surroundings and the light transmittance from the atrium.

It is recommended to consider multiple metrics to compare daylight level performances, since each metric can generate different data results [25]. Thus, four metrics are considered in the analysis: DA, $UDI_{<100}$, $UDI_{100-2000}$ and $UDI_{>2000}$.

DA (Daylight Autonomy) indicates the percentage of annual occupied hours at which a minimum level of illuminance can be maintained only by natural light [26]. An illuminance of 500 lux was considered for this metric, as recommended for office buildings [27].

UDI (Useful Daylight Illuminance) specifies the percentage of annual occupied hours at which the illuminance on a point is within a predefined range [28]. It was considered the illuminance ranges

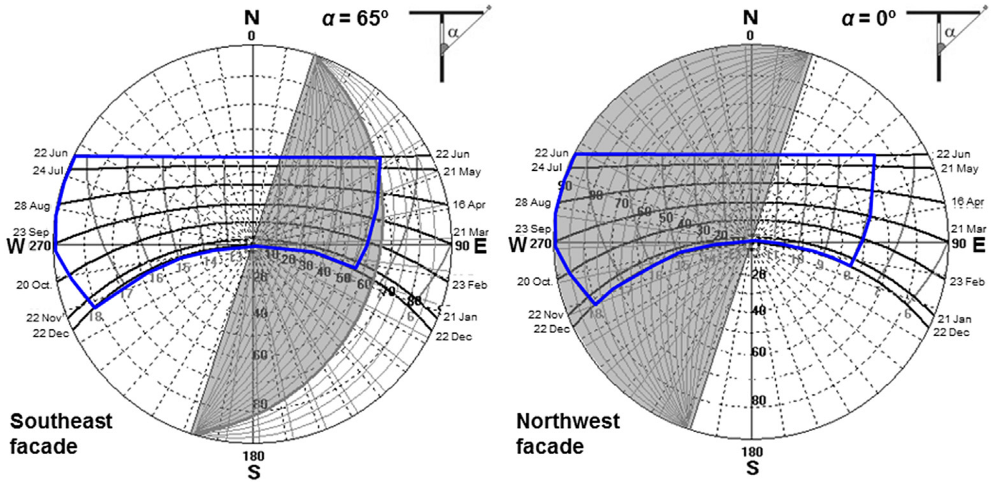


Fig. 2. Shading masks. In blue: building occupancy. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

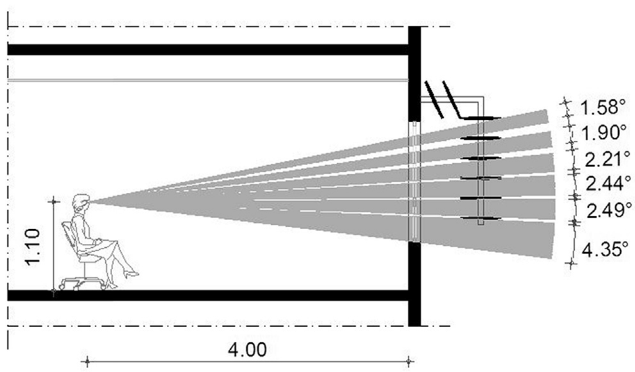


Fig. 3. Visual angles measurements.

provided by Daysim: $E < 100$ lux (insufficient), 100 lux $< E <$ 2000 lux (pleasant), and $E > 2000$ lux (uncomfortable).

In order to use the simulation results as input data for the multicriteria analysis, it is necessary to translate all the information provided by the software – for different metrics and multiple points – into a single value that represents the performance of each solution. Therefore, it is calculated the floor area occupied by a predefined range of DA and UDI.

Table 2
Surfaces optical properties.

Surfaces	Reflectance (%)	Visual transmittance (%)
Internal surfaces		
Wall	88	0
Floor	40	0
Ceiling	70	0
Envelope		
Overhang	88	0
Fins	70	0
Opaque facades	88	0
Opaque roof	88	0
Water tank, elevator machine room	88	0
Window frames	70	0
Glazed surfaces (facades)	–	46 or 78
Glazed surfaces (atrium)	–	78
Glazed roof (atrium)	–	72
Surroundings		
Buildings	65	0
Paving	65	0
Grass (back garden)	35	0

A criterion is established to define the minimum percentage of occupied hours, as the literature does not indicate reference values for a satisfactory range of DA and UDI [25]. Based on the orientation of the building main facades (Southeast and Northwest), it is considered as satisfactory a DA and UDI higher than 50%. This indicates that the daylight should be used in at least half of the hours of the building occupation, since the solar radiation will always reach one of the facades.

In order to measure the floor area occupied by the predefined range, it is created isocurve graphics, based on the spreadsheets provided by Daysim. The curves are defined for a range of 50% and the area occupied by a DA and UDI higher than 50% is highlighted (Fig. 4). Next, the graphics are exported to a CAD software to transform the curves into vectors and calculate the floor area of interest.

The floor areas in square meters represent the solutions performances for the four metrics. The greater the area covered by the range of 50–100% of DA and $UDI_{100-2000}$ and the smaller the area occupied by same range of $UDI_{<100}$ and $UDI_{>2000}$, the higher the solution daylight performance.

For the criterion of daylight level on work plan, since 4 sub-criteria are considered in the analysis, it is necessary to cross the results of the multiple metrics by means of the application of the same method described in the following step (Section 3.4). The same weight is indicated for all sub-criteria.

3.3.3. Energy efficiency assessment

The energy efficiency assessment is carried out by applying the prescriptive method from the Brazilian thermal regulation for commercial and public buildings, detailed by a document called RTQ-C [20].

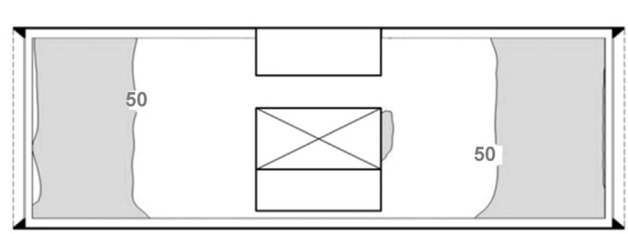


Fig. 4. Isocurve graphics for S2 (1st floor).

Table 3
Values introduced in Eq. (1).

Solution	HF	FF	WWR	WWR_w	SF	VSA	HSA
S1	0.075	0.17	0.09	0.37	0.37	0	3
S2	0.075	0.17	0.13	0.52	0.37	0	3
S3	0.075	0.17	0.09	0.37	0.70	45	3
S4	0.075	0.17	0.13	0.52	0.70	45	3
S5	0.075	0.17	0.09	0.37	0.70	40.08	3
S6	0.075	0.17	0.13	0.52	0.70	45	3

RTQ-C establishes requirements regarding the thermal properties of buildings components, including thermal transmittance, colors and surfaces absorbance, and solar factor for zenithal openings.

The regulation presents 8 different equations for each Brazilian bioclimatic zone to calculate the Envelope Consumption Index (ECI). It consists of a dimensionless index that combines some envelope parameters that influence the energy performance, such as the ones related to the building dimensions and openings.

These equations were developed by means of the statistical method of multiple linear regression based on a high number of annual thermal simulations on Energyplus, carried out with building prototypes representing the main typologies of office and public buildings in Brazil [29,30]. The following equation is an example applicable to buildings with an average floor area of over 500 m^2 located in the bioclimatic zone 8, which includes the Rio de Janeiro city.

$$\begin{aligned}\mathrm{ECI} = {} & -160.36\cdot \mathrm{HF} + 1277.29\cdot \mathrm{FF} - 19.21\cdot \mathrm{WWR} + 2.95\cdot \mathrm{SF} \\ & - 0.36\cdot \mathrm{VSA} - 0.16\cdot \mathrm{HSA} + 290.25\cdot \mathrm{FF}\cdot \mathrm{WWR} \\ & + 0.01\cdot \mathrm{WWR}\cdot \mathrm{VSA}\cdot \mathrm{HSA} - 120,58\end{aligned} \tag{1}$$

The Height Factor (HF) indicates the ratio of the roof projection area to the total construction area. The Form Factor (FF) represents the ratio of the envelope area to the building total volume. The solar factor (SF) indicates the ratio of the solar energy transmitted through the glass to the total solar energy incident on it. The Vertical Shade Angle (VSA) and the Horizontal Shade Angle (HSA) are the internal angles generated by vertical and horizontal shading devices, respectively.

The Window Wall Ratio (WWR) is calculated by the ratio of the sum of the total glazed surfaces area (frame excluded) to the total facade area of the building. In order to introduce the WWR value in the equation, it is required to calculate the west facade WWR (WWR_W), considering the glazed surface area and the facade area facing the west direction. If WWR_W exceeds in 20% the WWR, the WWR_W must be considered in the equation.

Table 3 shows the values of the variables inserted in Eq. (1) to calculate the Envelope Consumption Index (ECI).

As for the solutions 3, 4 and 6, VSA exceeds the safety limit value (45°) established to this equation by RTQ-C, their values are assumed as 45°.

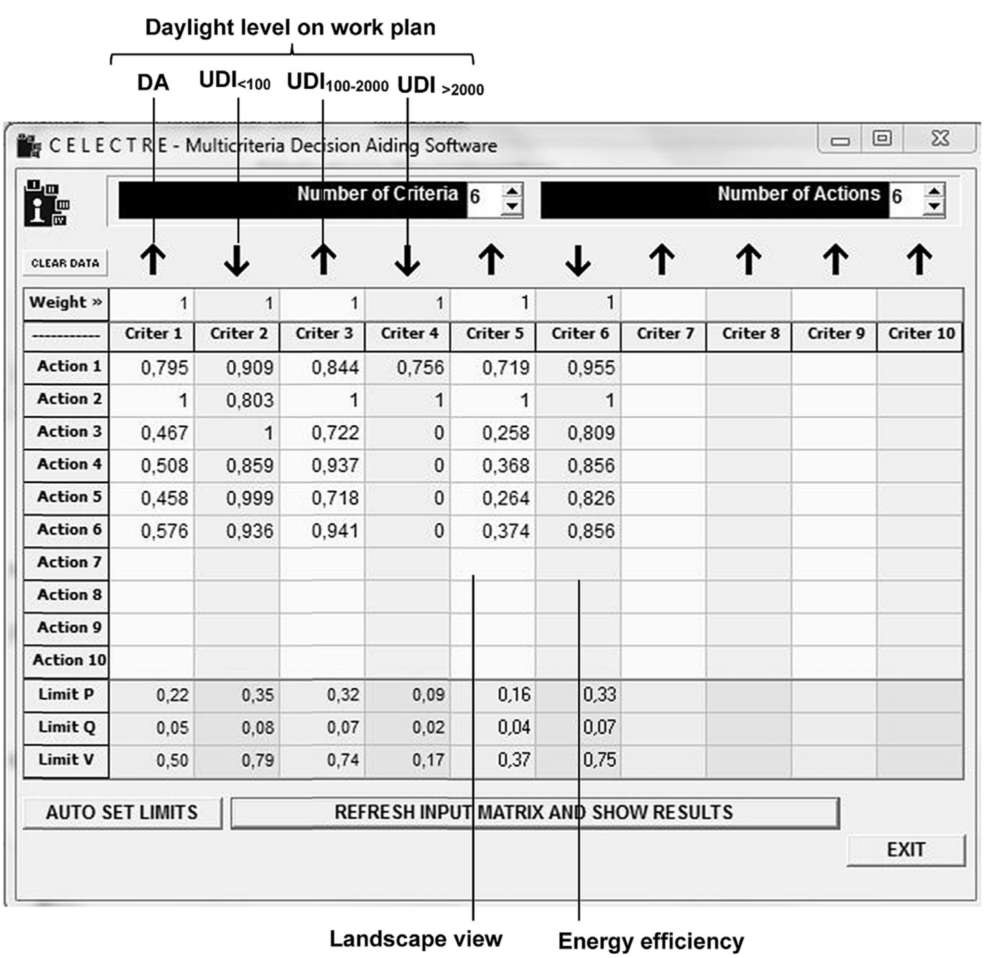


Fig. 5. CELECTRE main window.

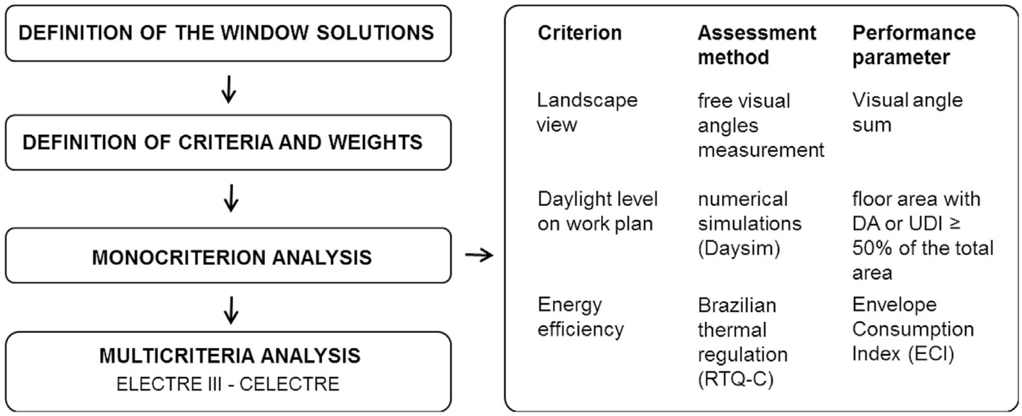


Fig. 6. Summary of the methodology steps.

3.4. *Application of a multicriteria method to identify the compromise solution*

Finally, after obtaining the monocriterion analysis results, the ELECTRE III method is applied [9] to identify the compromise solution, by means of the application of the software CELECTRE [2,18].

Fig. 5 shows the CELECTRE main window, where all normalized data results from the monocriterion analysis are introduced in the intersection between lines (solutions) and criteria (columns). Each of the 4 sub-criteria concerning the daylight level on work plan occupies a column.

The arrows above the columns indicate that for the sub-criteria DA and $UDI_{100-2000}$ and the landscape view criterion, the solution rating is directly proportional to the indicated performance values. In the same way, for the sub-criteria $UDI_{<100}$ and $UDI_{>2000}$ and the energy efficiency criterion, the solution rating is inversely proportional to the indicated performance values.

The weight values are introduced below the arrows, according to the weight scenarios. All daylight sub-criteria present the same weight.

The values of preference, indifference and veto are automatically defined by CELECTRE.

For each analyzed floor (3) and each weight scenario (13), all the described procedures are repeated, obtaining 39 cases of multicriteria analysis.

Fig. 6 summarizes the methodology steps described in this topic.

Table 4
Landscape view: results.

Solutions	SE facade	NW facade	Total (sum)	Normalized values	Partial ranking	
S1	20.42°	20.42°	40.84°	0.719	1st	S2
S2	28.39°	28.39°	56.78°	1.000	2nd	S1
S3	14.67°	0	14.67°	0.258	3rd	S6
S4	20.90°	0	20.90°	0.368	4th	S4
S5	14.97°	0	14.97°	0.264	5th	S5
S6	21.26°	0	21.26°	0.374	6th	S3

4. Results and discussion

4.1. *Monocriterion analysis results*

4.1.1. *Landscape view*

The results show that the solution S2 presents the highest performance in terms of landscape view, due to its dimensions and the inexistence of visual obstacles. The solutions with smaller openings present lower ratings, except S1, due to the inexistence of obstacles (Table 4).

Table 5
Daylight level: solutions raking by metric.

	DA (↑)		$UDI_{<100}$ (↓)		$UDI_{100-2000}$ (↑)		$UDI_{>2000}$ (↓)	
1st floor								
1st	S2	(137.97 m^2)	S2	(416.89 m^2)	S2	(338.78 m^2)	S3, S4, S5, S6	(0.00 m^2)
2nd	S1	(109.73 m^2)	S4	(446.10 m^2)	S6	(318.83 m^2)	S1	(2.17 m^2)
3rd	S6	(79.46 m^2)	S1	(472.08 m^2)	S4	(317.47 m^2)	S2	(2.87 m^2)
4th	S4	(70.08 m^2)	S6	(486.17 m^2)	S1	(317.47 m^2)	–	–
5th	S3	(64.48 m^2)	S5	(518.60 m^2)	S3	(244.44 m^2)	–	–
6th	S5	(63.13 m^2)	S3	(519.23 m^2)	S5	(243.40 m^2)	–	–
7th floor								
1st	S2	(160.73 m^2)	S2	(386.13 m^2)	S2	(360.85 m^2)	S3, S4, S5, S6	(0.00 m^2)
2nd	S4	(128.13 m^2)	S4	(405.21 m^2)	S4	(358.75 m^2)	S1	(8.17 m^2)
3rd	S6	(126.42 m^2)	S6	(414.48 m^2)	S6	(349.44 m^2)	S2	(10.67 m^2)
4th	S1	(124.50 m^2)	S1	(453.51 m^2)	S1	(299.71 m^2)	–	–
5th	S5	(94.71 m^2)	S5	(485.69 m^2)	S5	(278.12 m^2)	–	–
6th	S3	(93.25 m^2)	S3	(488.01 m^2)	S3	(276.50 m^2)	–	–
13th floor								
1st	S2	(209.80 m^2)	S2	(76.42 m^2)	S2	(668.55 m^2)	S3, S4, S5, S6	(0.00 m^2)
2nd	S4	(181.64 m^2)	S4	(157.31 m^2)	S4	(607.16 m^2)	S1	(12.29 m^2)
3rd	S6	(181.51 m^2)	S6	(172.64 m^2)	S6	(592.00 m^2)	S2	(19.64 m^2)
4th	S1	(173.58 m^2)	S1	(253.32 m^2)	S1	(496.03 m^2)	–	–
5th	S3	(148.60 m^2)	S3	(303.62 m^2)	S3	(461.10 m^2)	–	–
6th	S5	(145.55 m^2)	S5	(304.69 m^2)	S5	(459.69 m^2)	–	–

Table 6
Daylight level: results.

Solution	DA (↑)	$UDI_{<100}$ (↓)	$UDI_{100-2000}$ (↑)	$UDI_{>2000}$ (↓)	Partial ranking	
1st floor						
S1	0.795	0.909	0.844	0.756	1st	S6
S2	1.000	0.803	1.000	1.000	2nd	S4
S3	0.467	1.000	0.722	0	3rd	S3
S4	0.508	0.859	0.937	0	4th	S5
S5	0.458	0.999	0.718	0	5th	S2
S6	0.576	0.936	0.941	0	6th	S1
7th floor						
S1	0.775	0.929	0.829	0.766	1st	S6, S4
S2	1.000	0.791	1.000	1.000	2nd	S5
S3	0.580	1.000	0.766	0	3rd	S3
S4	0.797	0.830	0.994	0	4th	S2
S5	0.589	0.995	0.771	0	5th	S1
S6	0.787	0.849	0.968	0	6th	–
13th floor						
S1	0.827	0.831	0.742	0.626	1st	S6, S4
S2	1.000	0.251	1.000	1.000	2nd	S3
S3	0.708	0.996	0.690	0	3rd	S5
S4	0.866	0.516	0.908	0	4th	S2
S5	0.694	1.000	0.688	0	5th	S1
S6	0.865	0.567	0.885	0	6th	–

4.1.2. Daylight level on the work plan

Table 5 indicates the partial rankings for each metric, considering the floor area occupied by DA and UDI ≥50%. The different rankings confirm the importance of considering and crossing multiple metrics results to make a more consistent decision.

In all floors, the window solution S2 presents the best performance for DA, $UDI_{<100}$ and $UDI_{100-2000}$. On the other hand, it also presents the largest floor areas occupied by $UDI_{2000} \geq 50\%$, although it does not exceeds 2% of the analyzed area.

It is noticed that the 7th and the 13th floor rankings are identical for all metrics, except for $UDI_{>2000}$. This does not occur on the 1st floor.

Table 6 presents the single rankings for each floor, after crossing the results obtained for each metric by means of the application of the ELECTRE III method.

It can be verified that, although the solution S2 presents the best performance for 3 of the 4 sub-criteria, it reaches the penultimate position for all floors. This indicate the influence of its $UDI_{>2000}$ performance on the final result. This occurs even in cases when the area covered by DA and UDI ≥50% is insignificant compared to the total analyzed area. The significant reduction of its weight does not change the results. Therefore, it was decided to consider the results from the metric $UDI_{>2000}$ anyway, since excessive illuminances, even in small areas, can reduce the visual comfort for some users, affecting their productivity.

It was observed that S4 and S6 present the best rating for all floors, which highlight the importance of shading the openings to avoid excessive illuminances on the work plan. The larger dimension of these windows also contributes to their overall performance, especially when compared to their equivalent (A3 and A5, respectively).

For all floors, the solution S1 presents the worst overall performance, due to the occurrence of excessive illuminances for some regions of the work plan.

Table 7
Energy efficiency: results.

Solution	ECI	Normalized values	Partial ranking	
S1	96.24	0.955	1st	S3
S2	100.76	1.000	2nd	S5
S3	81.51	0.809	3rd	S4, S6
S4	86.23	0.856	4th	S1
S5	83.22	0.826	5th	S2
S6	86.23	0.856	6th	–

4.1.3. Energy efficiency

Table 7 indicates that the solutions with smaller WWR and with shading devices present a better performance than the ones not shaded. The same characteristics that make S2 the best solution in terms of landscape view – inexistence of shading devices and high WWR – provide a lower performance in terms of energy consumption, due to the high heat transfer by the windows. This is an example of conflict between criteria.

The solutions S4 and S6 reached the same rating, although they present different shading devices. This was caused by a limitation of the prescriptive method (RTQ-C), which is not sensible to the occurrence of air convection that may occur between the superior fins in the solution S6. The replacement of the S4 original VSA by

Table 8
Final rankings.

	All	Daylight level				Landscape view				Energy efficiency			
		2×	3×	4×	5×	2×	3×	4×	5×	2×	3×	4×	5×
1st floor													
1st	S6	S6	S6	S6	S6	S6	S6	S6	S6	S6	S6	S6	S6
2nd	S4	S4	S4	S4	S4	S4	S4	S4	S4	S4	S4	S4	S4
3rd	S1	S3	S3	S3	S3	S1	S1	S1	S1	S3	S3	S3	S3
4th	S3	S5	S5	S5	S5	S5	S5	S2	S2	S5	S5	S5	S5
5th	S5	S1	S1	S1	S1	S3	S3	S5	S5	S1	S1	S1	S1
6th	S2	S2	S2	S2	S2	S2	S2	S3	S3	S2	S2	S2	S2
7th floor													
1st	S6, S4	S6, S4	S6, S4	S6, S4	S6, S4	S6, S4	S6, S4	S6, S4	S6, S4	S6, S4	S6, S4	S6, S4	S6, S4
2nd	S5	S5	S5	S5	S5	S1	S1	S1	S1	S5	S5	S5	S5
3rd	S3	S3	S3	S3	S3	S5	S2	S2	S2	S3	S3	S3	S3
4th	S1	S2	S2	S2	S2	S3	S5	S5	S5	S2	S2	S2	S2
5th	S2	S1	S1	S1	S1	S2	S3	S3	S3	S1	S1	S1	S1
6th	–	–	–	–	–	–	–	–	–	–	–	–	–
13th floor													
1st	S6, S4	S6, S4	S6, S4	S6, S4	S6, S4	S6, S4	S6, S4	S6, S4	S6, S4	S6, S4	S6, S4	S6, S4	S6, S4
2nd	S2	S2	S2	S2	S2	S2	S2	S2	S2	S2	S3	S3	S3
3rd	S3	S3	S3	S3	S3	S1	S1	S1	S1	S3	S5	S5	S5
4th	S5	S5	S5	S5	S5	S5	S5	S5	S5	S5	S2	S2	S2
5th	S1	S1	S1	S1	S1	S3	S3	S3	S3	S1	S1	S1	S1
6th	–	–	–	–	–	–	–	–	–	–	–	–	–

the limit value imposed by the method also contributed to equalize the performances.

4.2. Multicriteria analysis results

Table 8 presents the multiple final rakings obtained for each weight scenario. Each column indicates the ranking considering a criterion prioritized at a time, attributing a weight 2, 3, 4 or 5 times greater than the others.

The results indicate that the only solution that keeps the same place (1st) for all weight scenarios is S6. For the 7th and 13th floor, S4 also presents the highest overall performance.

When analyzing the partial rankings obtained from the monocriterion analysis (Tables 4, 6 and 7), it is concluded that the simple comparison between rankings does not allow identifying the compromise solution. The solutions S4 and S6, for example, only present the best performances in terms of daylight level on work plan. In the same way, the solutions S2 and S3 reach the first place for different criteria, however, they do not present an outstanding overall performance.

The results are not always sensible to the weights attributed to the criteria. For the 1st and 7th floor, when prioritizing the criteria daylight level and energy efficiency, identical rankings are obtained for different weight scenarios, however, for the landscape view, they present some differences. For the 13th floor, the prioritization of the energy efficiency criterion results in different rankings.

Besides the ranking diversity, it is possible to identify the compromise solution for this multicriteria analysis: the solution S6. Although not reaching the first place for all floors, the solution S4 also presents an outstanding overall performance and consists in a good choice.

If the rankings of all floors indicated different compromise solutions, it would be prudent to consider adopting different solutions for groups of floors, if this decision was in accordance with the design language proposed for the building and with the restrictions imposed by developers and builders.

Furthermore, in a real decision scenario, if different compromise solutions were identified, one should consider giving priority to the landscape view, as this specificity adds high value to the building not only in terms of price but also in terms of occupant's satisfaction.

5. Conclusions

This work attests the influence of windows on the energetic and environmental quality of buildings. It highlights the complexity encountered in its design process, emphasizing the importance of conceiving them by a holistic approach. The multicriteria approach is pointed out as one of the possible ways to achieve this goal, and an application of one of its methods (ELECTRE III) is carried out to aid the architecture conception of windows for an office building sited in Rio de Janeiro city.

Some important conclusions about the six proposed architectural solutions were obtained. It was verified that the shaded solutions presented a more satisfactory overall performance than the ones not shaded, even when adopting a solar control glass instead of a solar protection. Furthermore, due to the size and shape of the studied space, larger openings presented better overall results. Besides increasing the landscape view, these solutions allow incrementing the daylight level in areas far from the windows. In the shaded solutions, the advantages overweighed the impacts caused by the building high heat gains, indicated by the energy consumption.

Regarding the 4 steps of the multicriteria analysis, one of the greatest difficulties consists in creating or interpreting existing methods in order to obtain a single performance reference value for each criterion. It was also verified that some monocriterion analysis may be turned into multicriteria analysis, making the assessment even more complex.

It was observed that a simple comparison between the rankings from the monocriterion analysis, in many cases, does not allow identifying the final ranking and the compromise solution, mainly when criteria present conflicts between them, as in the studied case.

It is concluded that the multicriteria approach is a very effective way to analyze more consistently the solutions proposed for a problem and to assist designers to minimize the conflicts between criteria. It allows performing an integrated approach, enabling a more conscious, accurate and responsible decision making.

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